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13. ABSTRACT ***(Maximum 200 Words)***

This presentation includes technical comparisons of different atmospheric modelling instruments. For this report, results of the DBIS (Double Input Beam Interferometer Sounder) were compared to models such as FASCOD3 and MODTRAN2/L.

The goal of this project was the retrieval of atmospheric temperature and water vapor profiles and possibly over relevant information on clouds and aerosol properties from high resolution IR emission measurements with a ground-based infereometer.

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RETRIEVAL OF TROPOSPHERIC PROFILES FROM IR EMISSION SPECTRA:

FIELD EXPERIMENT AND SENSITIVITY STUDY

Preliminary Results with the DBIS

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Univ. of Tromsö
Tromsö, Norway

30 June 1993

RETRIEVAL OF TROPOSPHERIC PROFILES FROM IR EMISSION SPECTRA: INVESTIGATIONS WITH THE DOUBLE BEAM INTERFEROMETER SOUNDER (DBIS)

by

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Presented at the

**1993-Optical Remote Sensing of the Atmosphere
Salt Lake City, Utah
March 8-12, 1993**

TOPICS

- **GOAL OF THE PROJECT:**

  Retrieval of atmospheric temperature and water vapor profiles and possibly other relevant information on clouds and aerosol properties from high resolution IR emission measurements with a ground-based interferometer.

- **TARGET APPLICATIONS:**

  Decision Aids that integrate environmental information to predict atmospheric transmission and refraction effects (IR, radar, acoustic..)

- **EXPERIMENTAL ASPECTS:**
  - Instrument (DBIS)
  - Measurements (SUDBURY, MA)

- **COMPARISONS WITH MODELS:**
  - FASCOD3
  - MODTRAN 2/L

- **ELABORATION OF A RETRIEVAL PROCEDURE:**
  - Minimum Information Type
  - Simultaneous Retrieval of T and H_2O Profiles for Hot-Dry / Wet Cases

DBIS OUTLINE

DBIS- Double input Beam Interferometer Sounder

1 - One or two Cassegrain 10-in diameter F/5.1 telescopes with slant path capability

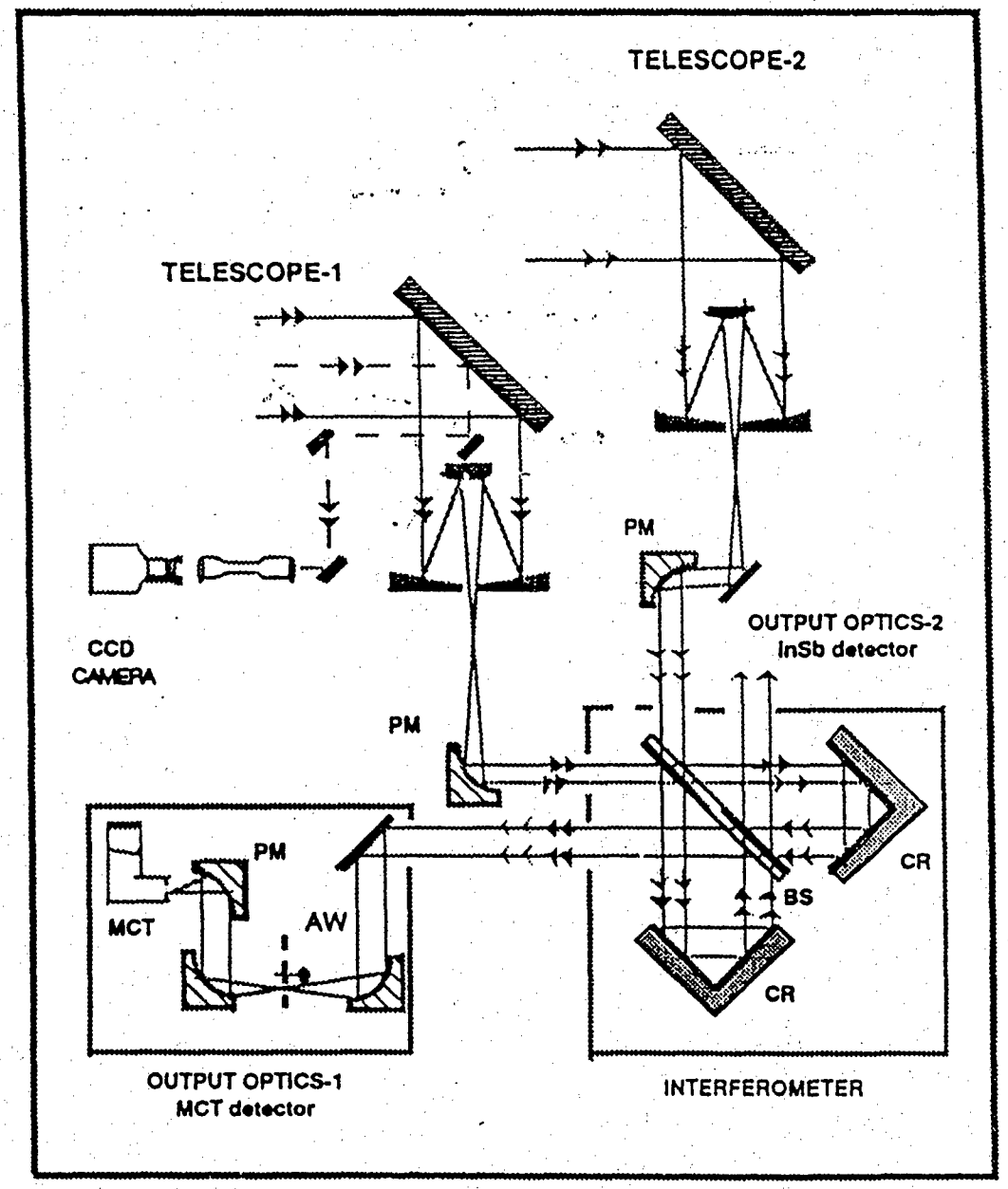
2 - BOMEM Michelson MB-100 Interferometer:
- Double Input Double Output (Corner Reflectors)
- Resolution from 1 cm^{-1} to 128 cm^{-1}
- Clear optical beam cross section ~14 cm^2
- Channel-1 (MCT): 5-20 μm, KBr Beamsplitter
- Channel-2 (InSb): 2-5 μm

3 - System field of view: 5 mrad or smaller

4 - Calibration: Two temperatures method- Using two 12-in Flat plate blackbodies (ambient and 50° C)

3 -Measured RMS-noise: < 0.2 K for a 2 min. recording at 1 cm-1 res.

DOUBLE BEAM INTERFEROMETER SOUNDER (DBIS)



SUDBURY FIELD EXPERIMENT

1 - ORGANIZED BY: Phillips Lab. (Hanscom AFB)

2 - DATE: From May to July 1992

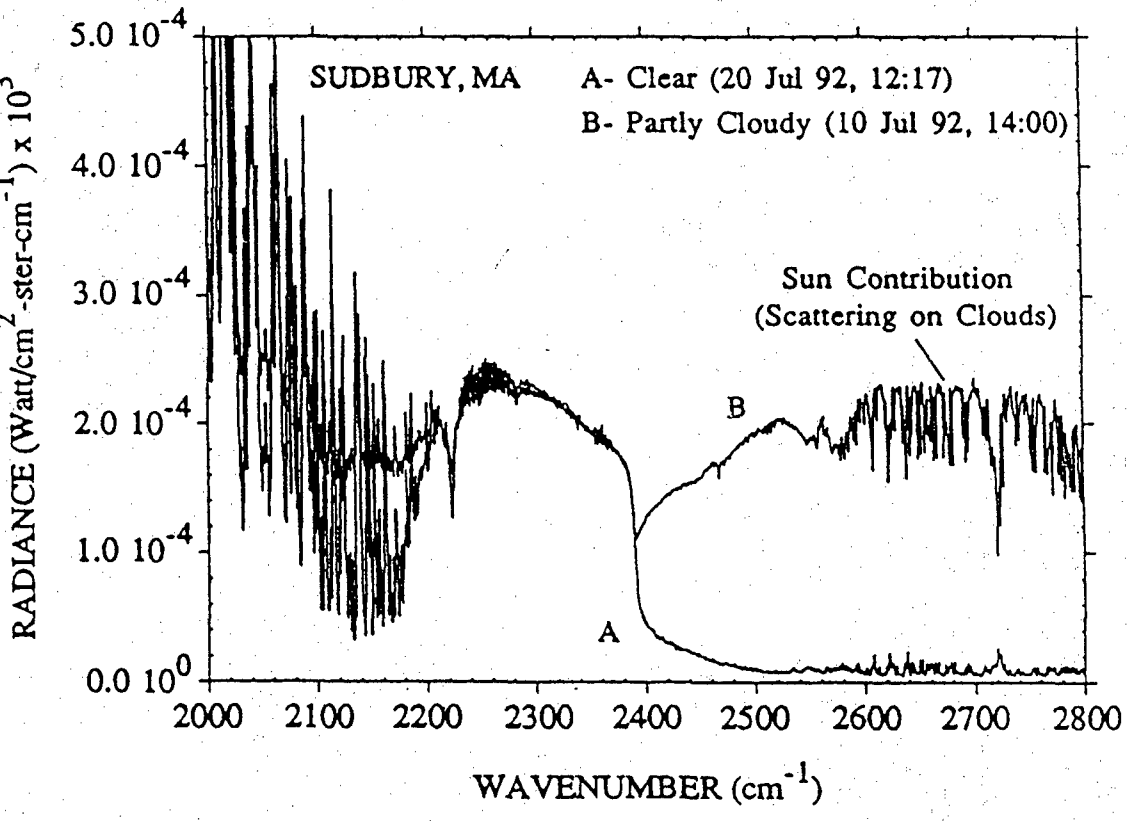
3 - LOCATION: Ft. Devens annex in Sudbury, MA

4 - OBJECTIVE: Simultaneous measurements of spectroscopic and scattering properties of the atmosphere in clear and cloudy conditions with simultaneous visible and IR imagery.

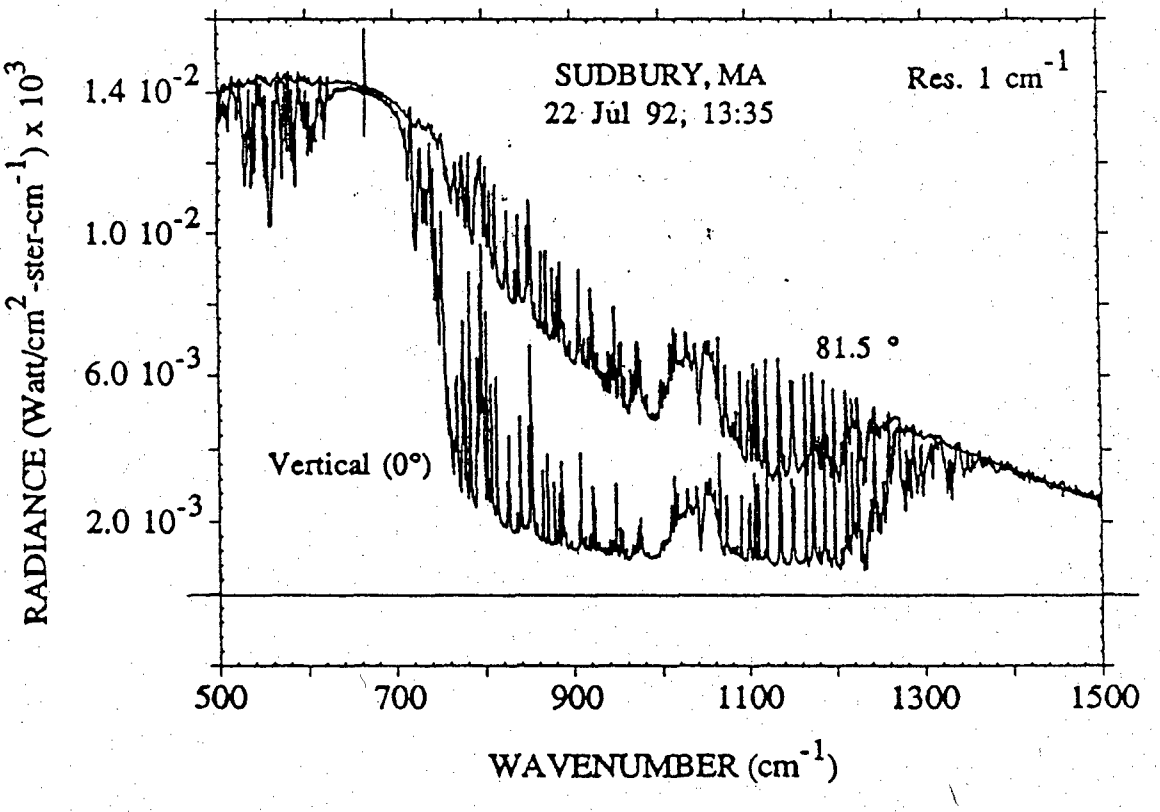
5 - INSTRUMENTATION:

- Nd: YAG lidar: λ, .532 and 1.06 μm (Phillips Lab.)
- TPQ11 Radar: 35 GHz (PL)
- All Sky Camera: Visible (PL)
- IR Imager: 3-5 μm region (PL)
- Visible Imager: (PL)
- Radiosondes and Met Station (PL)
- DREV-Interferometer (DBIS): 3-20 μm, 1 cm^{-1} Res.

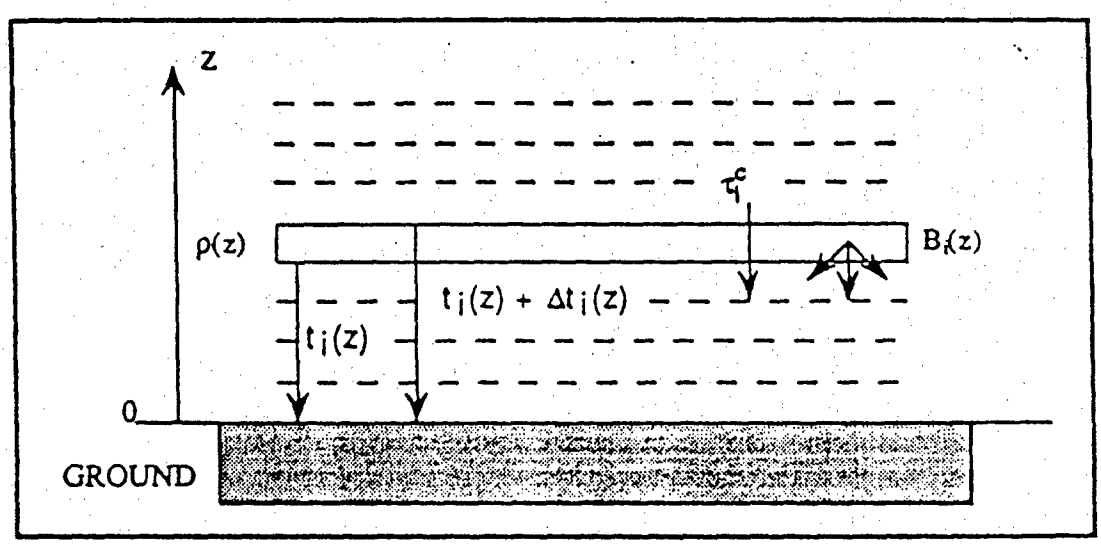
EMISSION SPECTRA IN THE MID-IR:
DREV-MEASUREMENTS (DBIS) IN CLEAR AND CLOUDY CONDITIONS



ATMOSPHERIC SLANT PATH IR EMISSION SPECTRA:
MEASURED WITH THE DREV-INTERFEROMETER (DBIS)
IN HOT-DRY CONDITIONS FOR 2 ZENITH ANGLES



RADIATIVE TRANSFER IN THE ATMOSPHERE



TOTAL RADIANCE (at wavenumber ν_i) :

$$R_i = - \int B_i(z) \; d\left[t_i(z)\right]$$

or

$$R_i = - \int B_i(z) \frac{\partial t_i(z)}{\partial z} d(z)$$

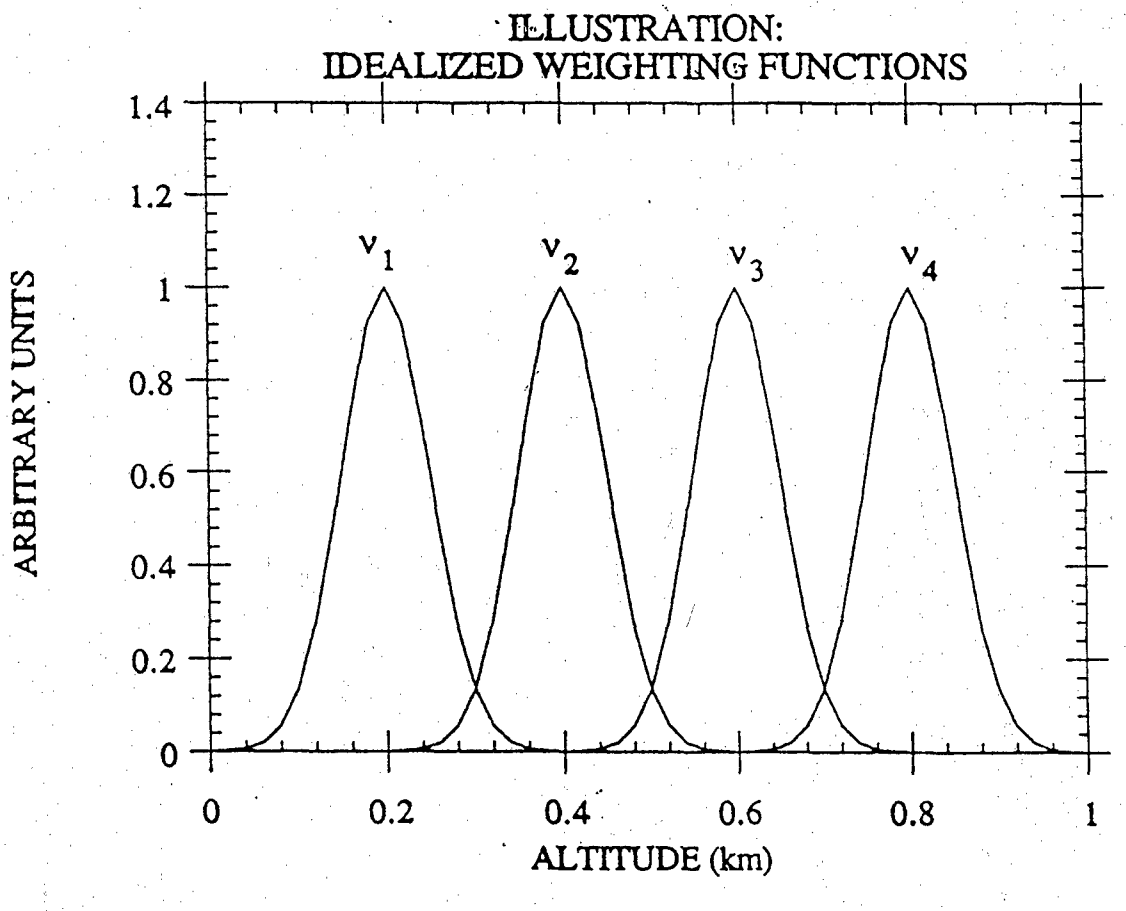
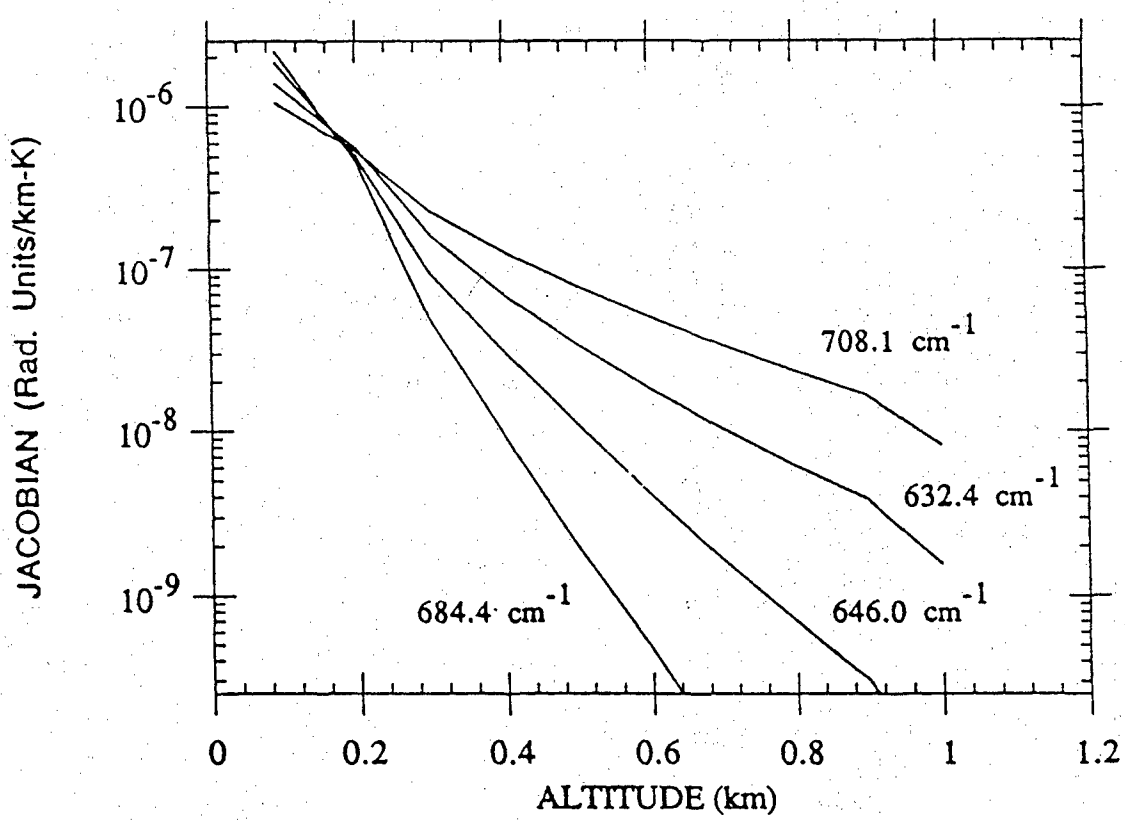


ILLUSTRATION:
IDEALIZED WEIGHTING FUNCTIONS
ARBITRARY UNITS
1.4
1.2
1
0.8
0.6
0.4
0.2
0
ν_1
ν_2
ν_3
ν_4
0
0.2
0.4
0.6
0.8
1
ALTITUDE (km)

ALTITUDE DEPENDENCE OF THE WEIGHTING FUNCTION
FOR 4 WAVENUMBERS IN THE 15 MICRON REGION



THE INVERSE PROBLEM:
GENERAL RETRIEVAL METHODS

---

1 - Statistical Methods: A priori Information

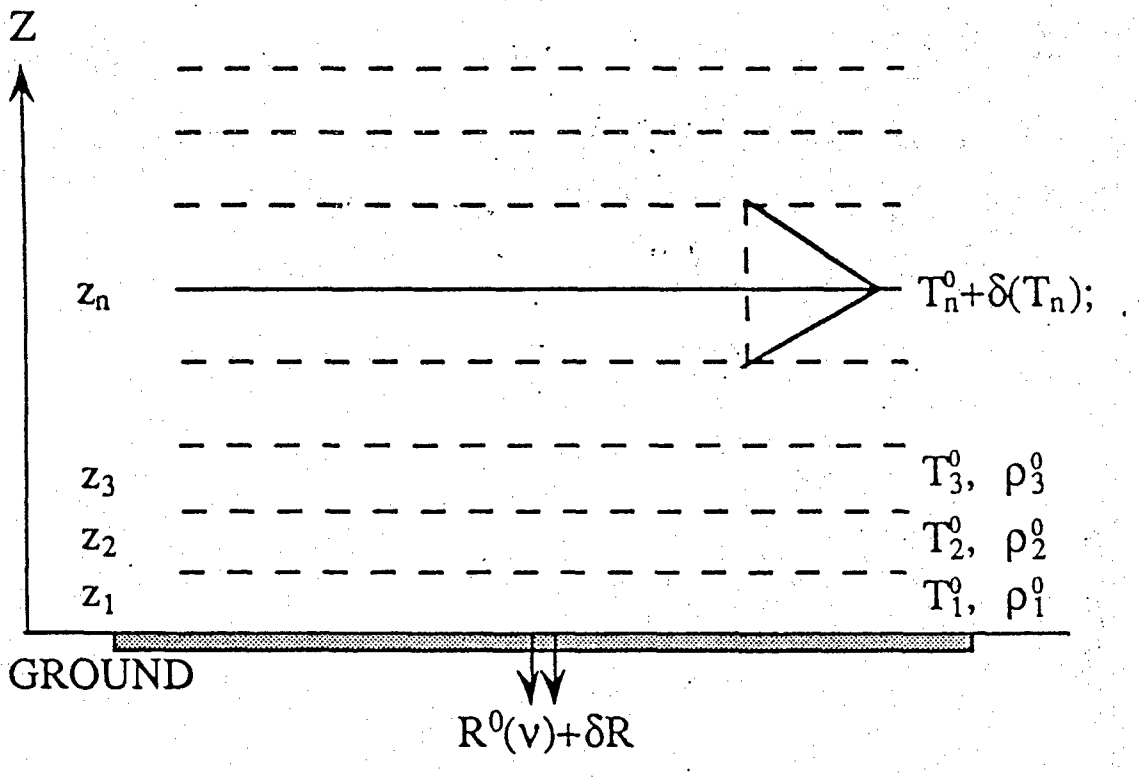
- Regression (Pure Statistical)
- Maximum Likelihood (Physical- Statistical)

2 - Physical Methods: No a priori statistics

- Nonlinear Iterative (Physical)
  a) Time consuming for high resolution spectra (~ 2000 elements)
  b) Easy to implement

- Minimum Information (Physical)
  a) Simultaneous retrieval of T and constituents profiles (possible)
  b) Can handle large number of spectral elements

PERTURBATION OF THE RADIATIVE TRANSFER EQUATION (RTE)



- T^0, ρ^0 .... First Guess Profiles (Inputs)
- R^0 ..... Computed Radiance with First Guess Profiles

- T, ρ ..... Unknown profiles (solution) ??
- R ..... Measurements (or simulation)

- **PERTURBATION:** $R(\nu) = R^0(\nu) + \delta R(\nu)$

RTE-INVERSION :
MINIMUM INFORMATION SOLUTION

- **Taylor expansion:**

$$\delta R(v) = \left(\frac{\partial R^0}{\partial T_1}\right)\delta T_1 + \left(\frac{\partial R^0}{\partial T_2}\right)\delta T_2 + \ldots \left(\frac{\partial R^0}{\partial T_L}\right)\delta T_L + \ldots$$

$$+ \left(\frac{\partial R^0}{\partial \rho_1}\right)\delta \rho_1 + \left(\frac{\partial R^0}{\partial \rho_2}\right)\delta \rho_2 + \ldots \left(\frac{\partial R^0}{\partial \rho_L}\right)\delta \rho_L$$

- **Matrix form:**

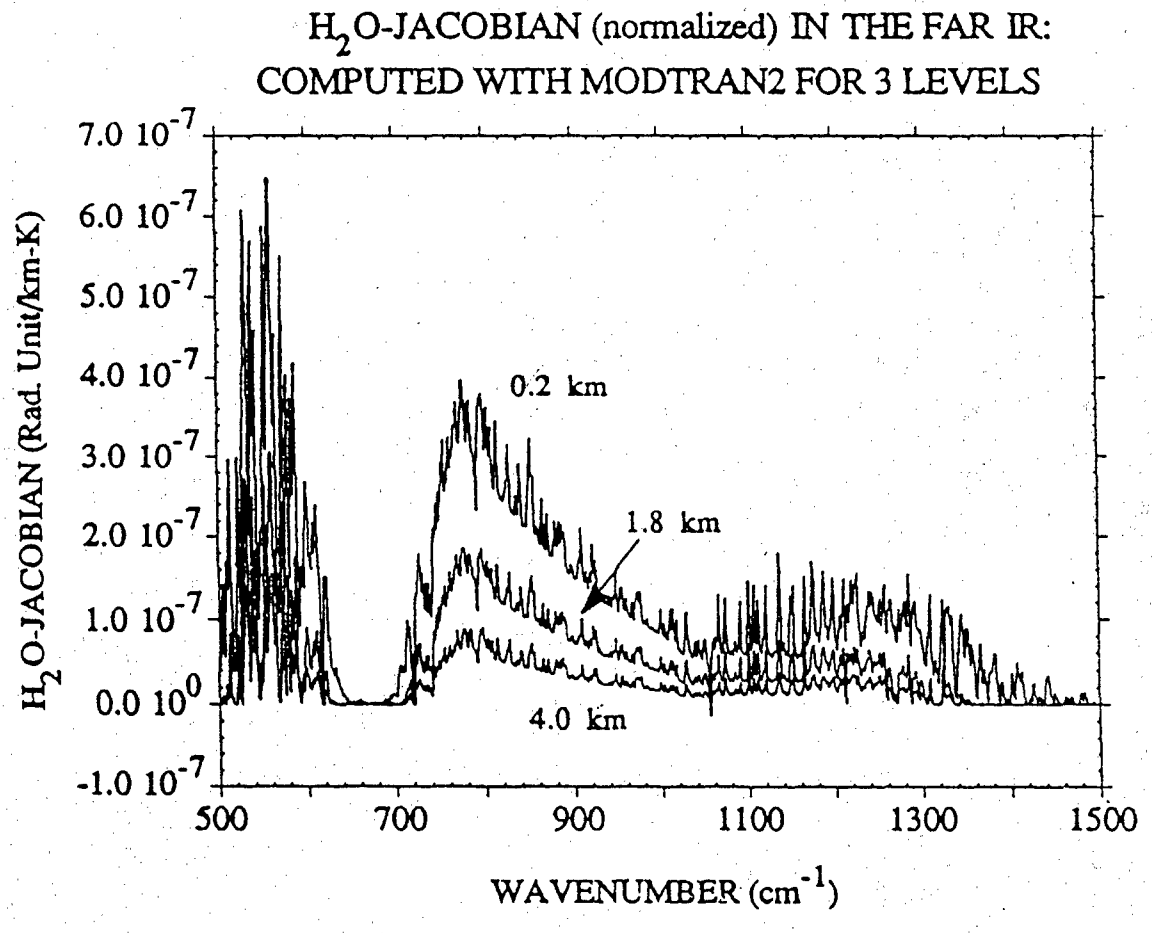
$$r = K\,x$$

x... Profiles solution (~ 40 + 40 lines)
r ... Measurements (column ~ 2000 spectral elements)
K... Partial derivatives or Jacobian (~ 2000 lin x 80 col)

- **Minimum Information Solution** of this overdetermined system:

$$x = \left[K^t S_e^{-1} K + S_b^{-1} \right]^{-1} K^t S_e^{-1} r$$

S_e ... Diagonal matrix: Noise standard deviation σ_i^2.
S_b ... Diagonal matrix: Damping Factor (OPTIMIZATION..)


H2O-JACOBIAN (normalized) IN THE FAR IR:
COMPUTED WITH MODTRAN2 FOR 3 LEVELS
H2O-JACOBIAN (Rad. Unit/km-K)
7.0 10-7
6.0 10-7
5.0 10-7
4.0 10-7
3.0 10-7
2.0 10-7
1.0 10-7
0.0 100
-1.0 10-7
0.2 km
1.8 km
4.0 km
500
700
900
1100
1300
1500
WAVENUMBER (cm-1)

RETRIEVAL METHODOLOGY

---

1 - FIRST GUESS ESTIMATION PROCEDURE :

- **Temperature** : Interpolation from profiles evaluated near the surface (< 0.5 km) and > 10km (Mid-Sum).

- **H_2O Mixing Ratio** : Arithmetic average of Mid-Sum and US std profiles scaled with the IR emission near 560 cm-1.

2 - RETRIEVAL PROCEDURE AND RESULTS:

- K matrix derived from FASCODE optical depth ; RTE includes "linear in τ"; Variable resolution

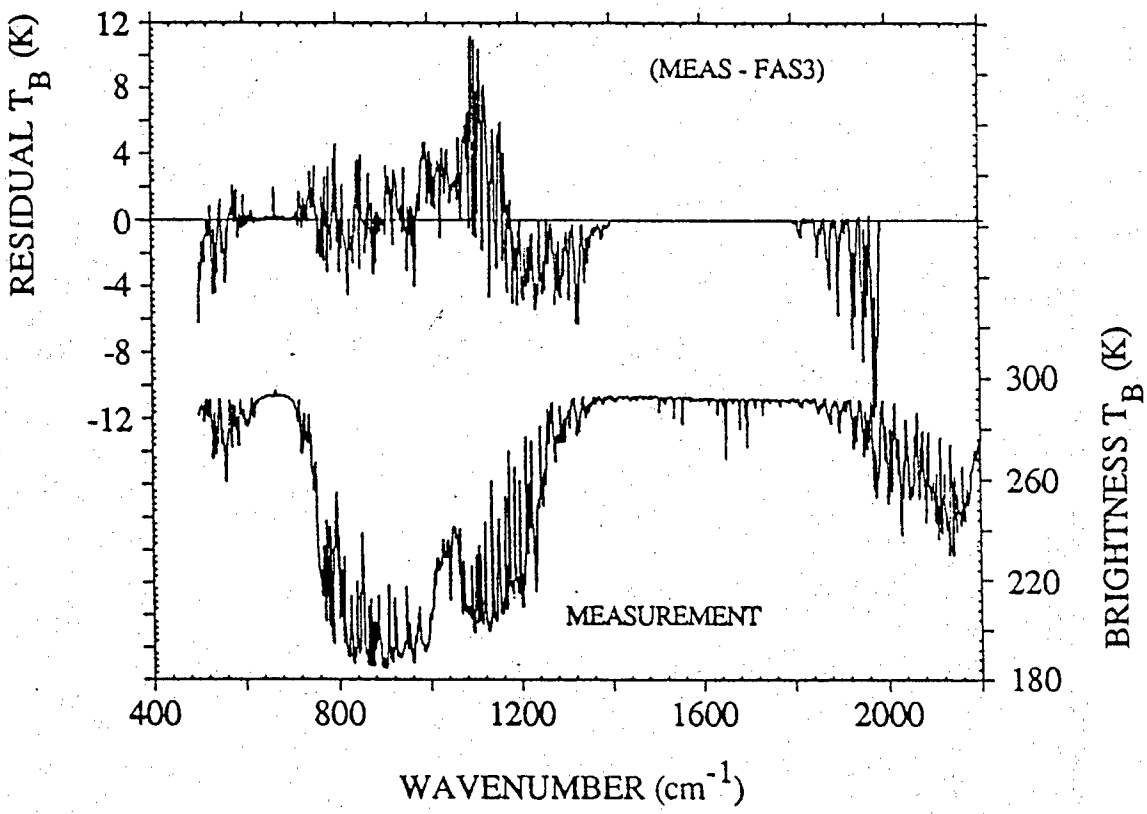
- Optimization of damping factors

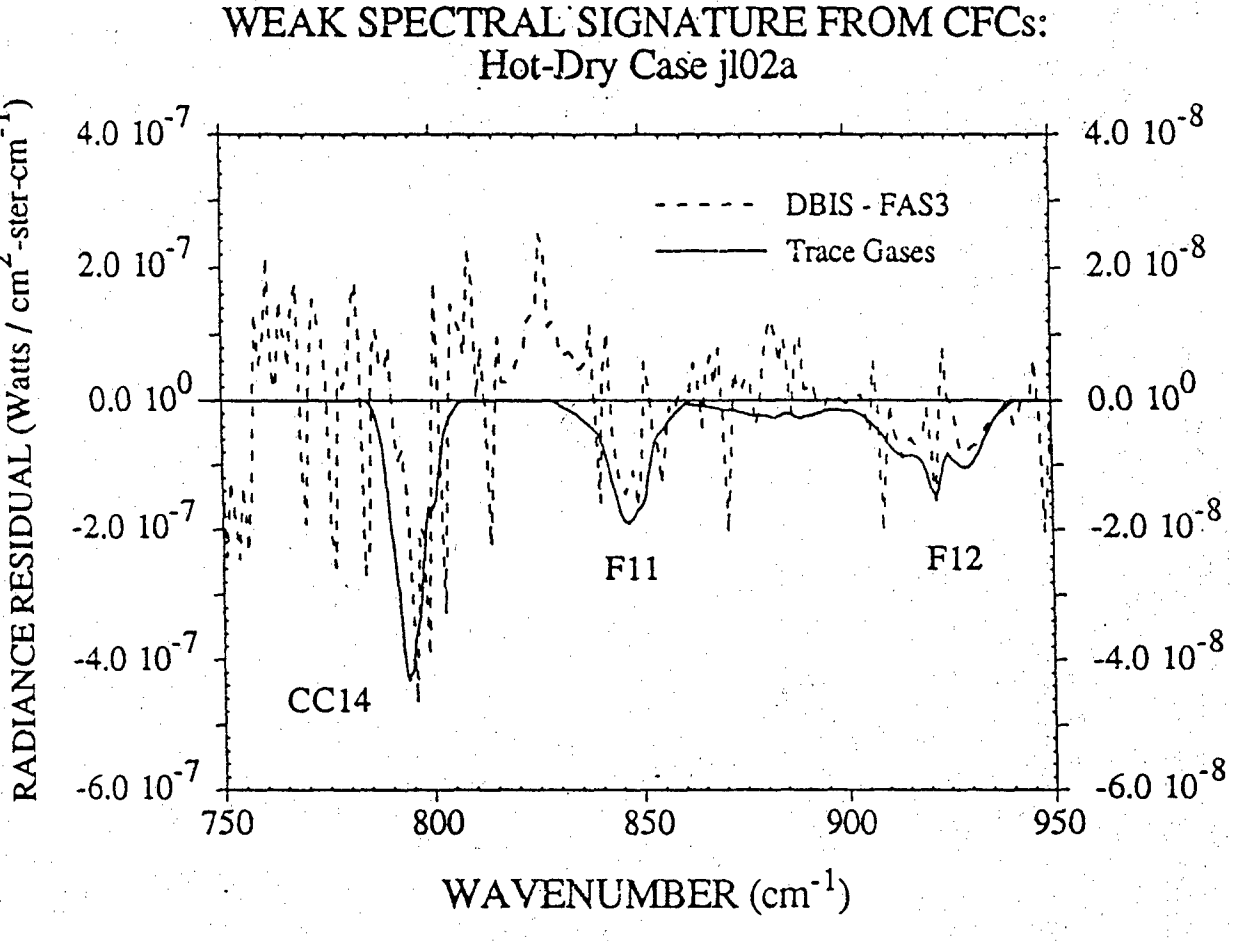
- Spectral screening based on residual analysis ; H_2O Continuum correction

- Results for hot-dry and hot-wet cases

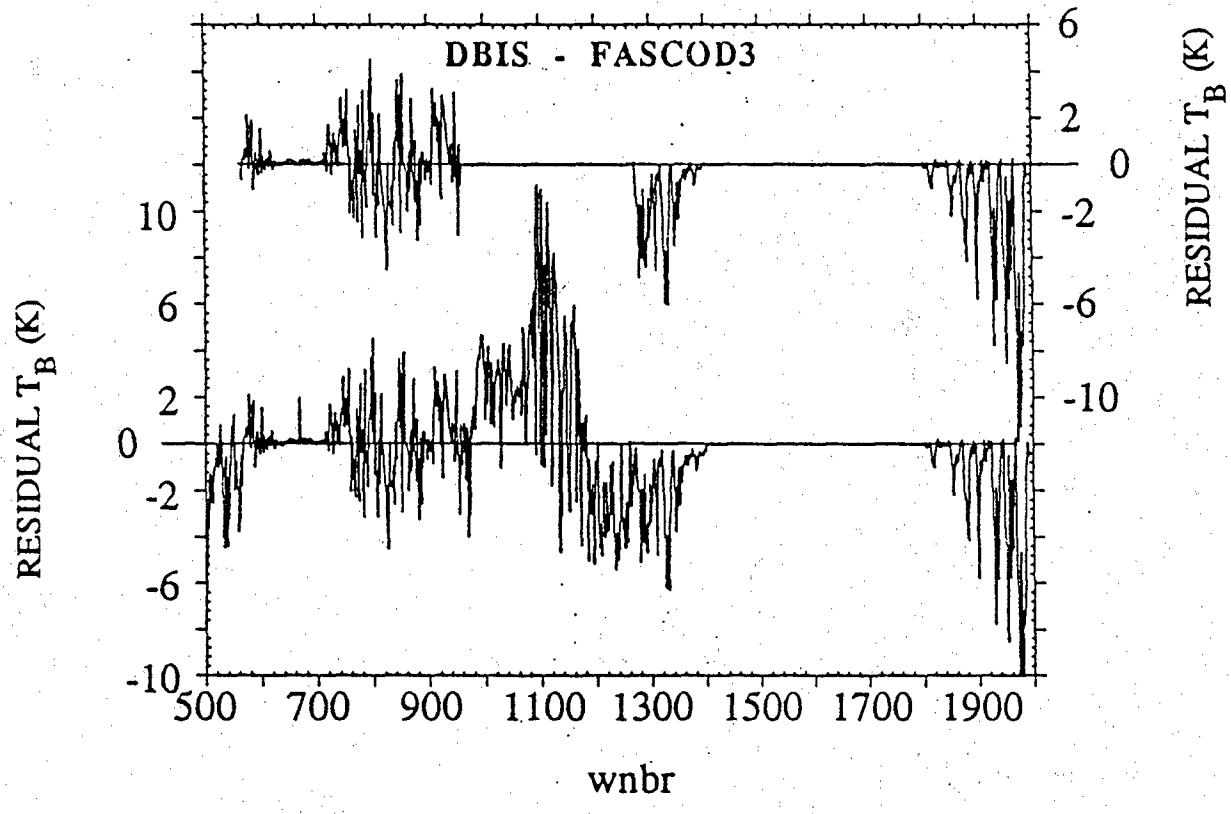
- Use of MODTRAN L Jacobian

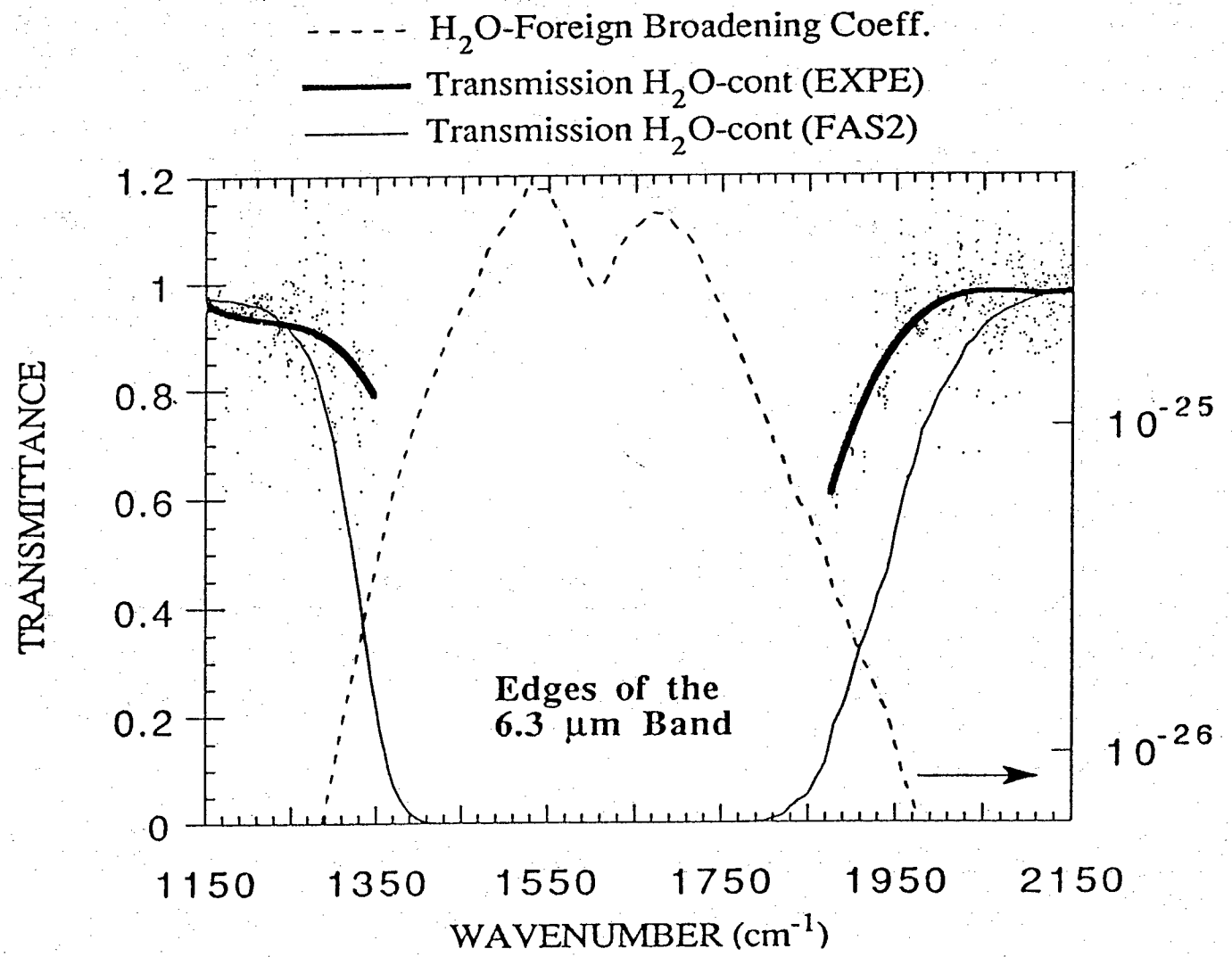
SPECTRAL RESIDUAL
FOR THE HOT-DRY CASE JL02A

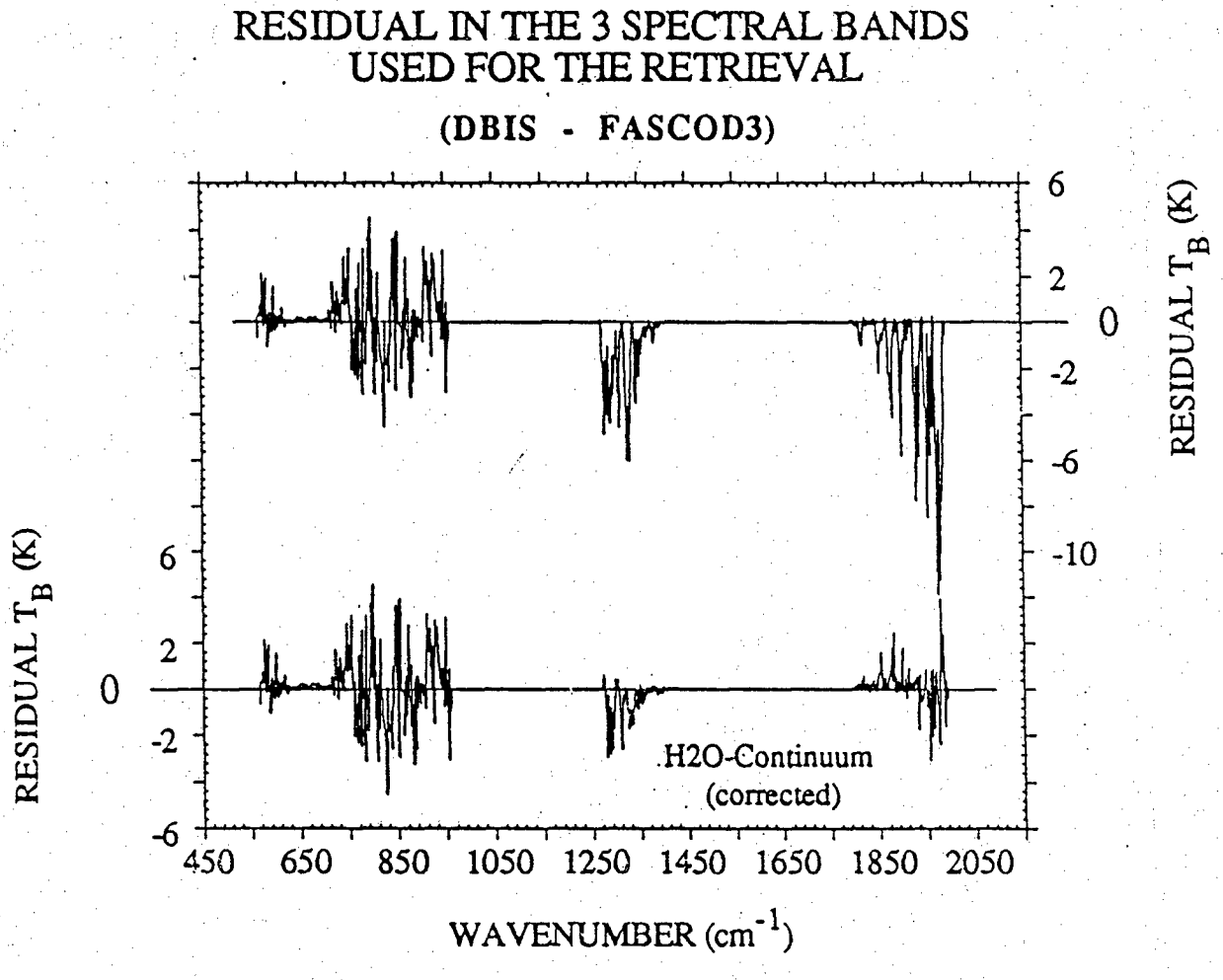



WEAK SPECTRAL SIGNATURE FROM CFCs:
Hot-Dry Case jl02a
RADIANCE RESIDUAL (Watts / cm^2-ster-cm^{-1})
4.0 10^{-7}
2.0 10^{-7}
0.0 10^0
-2.0 10^{-7}
-4.0 10^{-7}
-6.0 10^{-7}
4.0 10^{-8}
2.0 10^{-8}
0.0 10^0
-2.0 10^{-8}
-4.0 10^{-8}
-6.0 10^{-8}
DBIS - FAS3
Trace Gases
CC14
F11
F12
750
800
850
900
950
WAVENUMBER (cm^{-1})

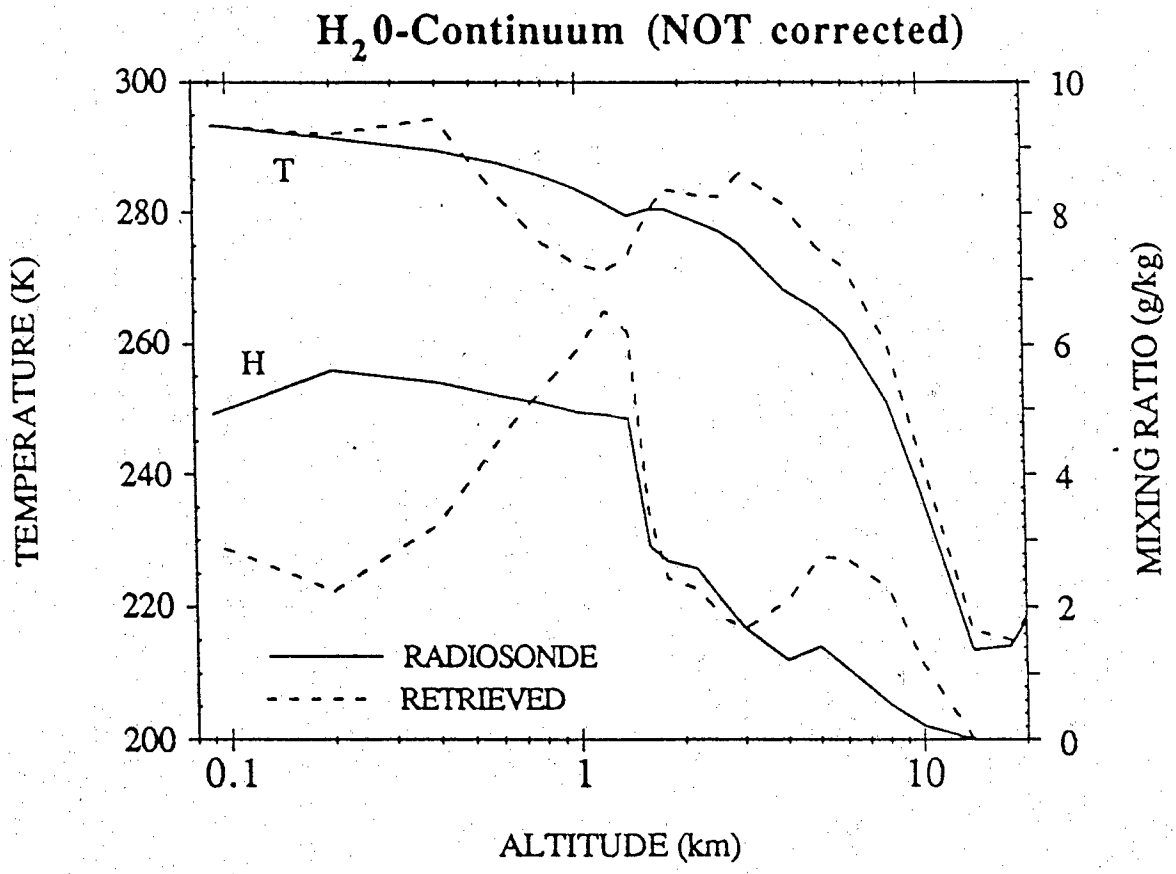
RESIDUAL IN THE 3-SPECTRAL BANDS
USED FOR THE RETRIEVAL:
No Continuum Correction



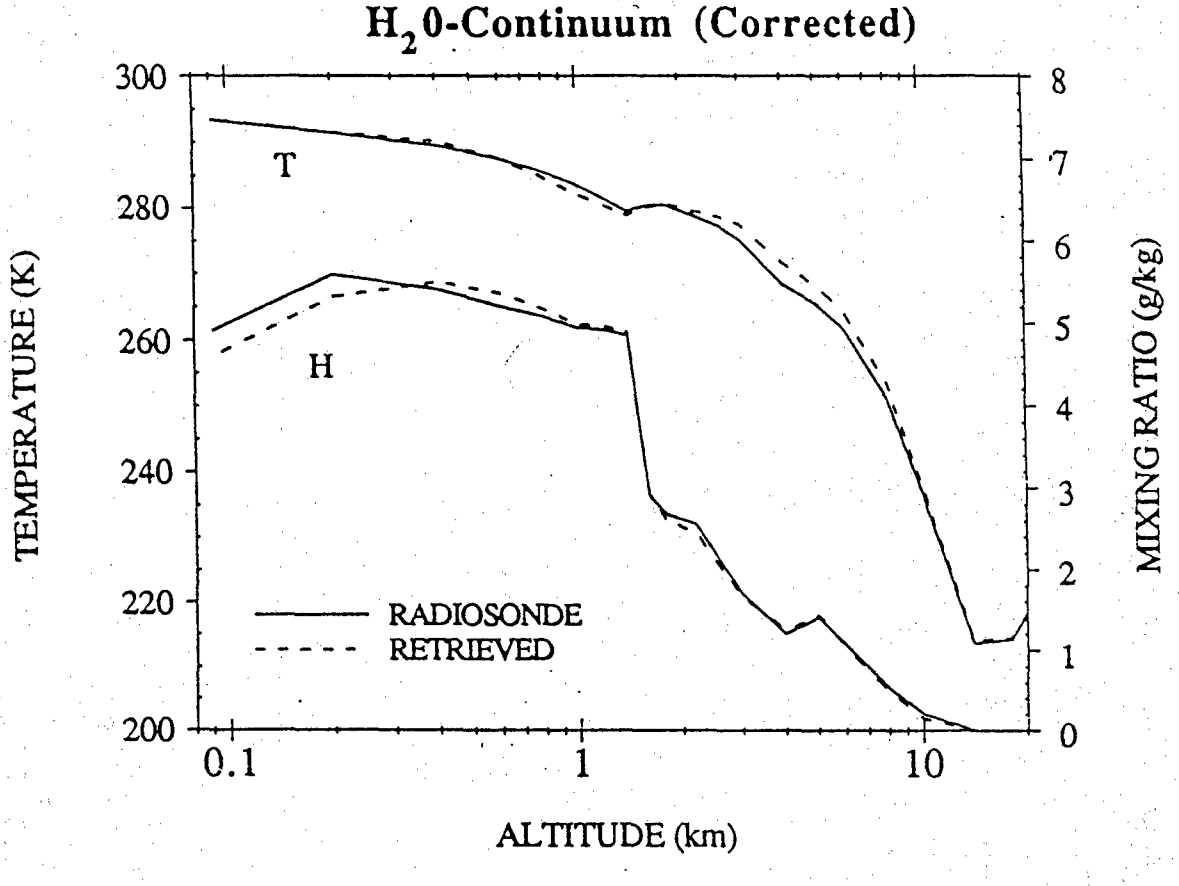

H_2O-Foreign Broadening Coeff.
Transmission H_2O-cont (EXPE)
Transmission H_2O-cont (FAS2)
TRANSMITTANCE
1.2
1
0.8
0.6
0.4
0.2
0
10^{-25}
10^{-26}
Edges of the
6.3 µm Band
1150
1350
1550
1750
1950
2150
WAVENUMBER (cm^{-1})


RESIDUAL IN THE 3 SPECTRAL BANDS
USED FOR THE RETRIEVAL
(DBIS - FASCOD3)
RESIDUAL T_B (K)
RESIDUAL T_B (K)
6
2
0
-2
-6
-10
6
2
0
-2
-6
H2O-Continuum
(corrected)
450
650
850
1050
1250
1450
1650
1850
2050
WAVENUMBER (cm^{-1})

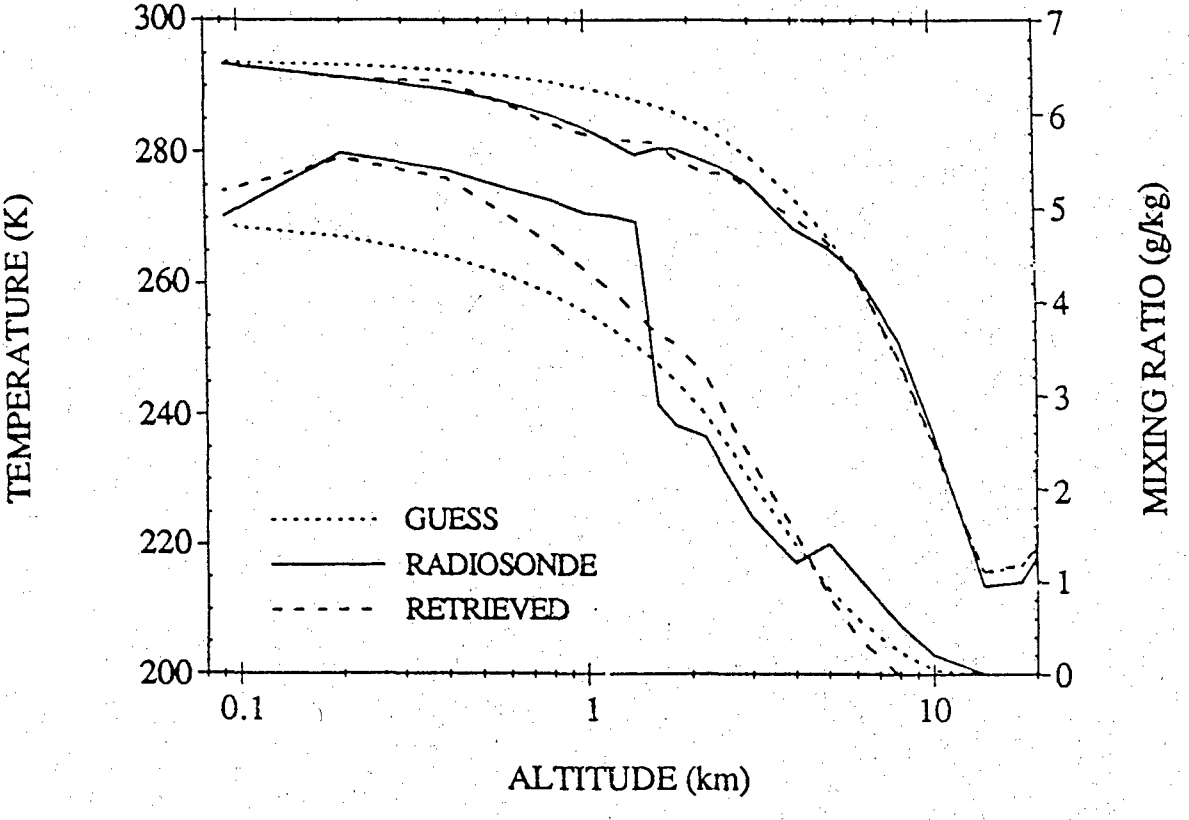
SIMULTANEOUS RETRIEVAL FROM MEASUREMENT jl02a:
709 Spectral Channels : First Guess= Radiosonde : Tuned Damp-Factor (4,100,2)



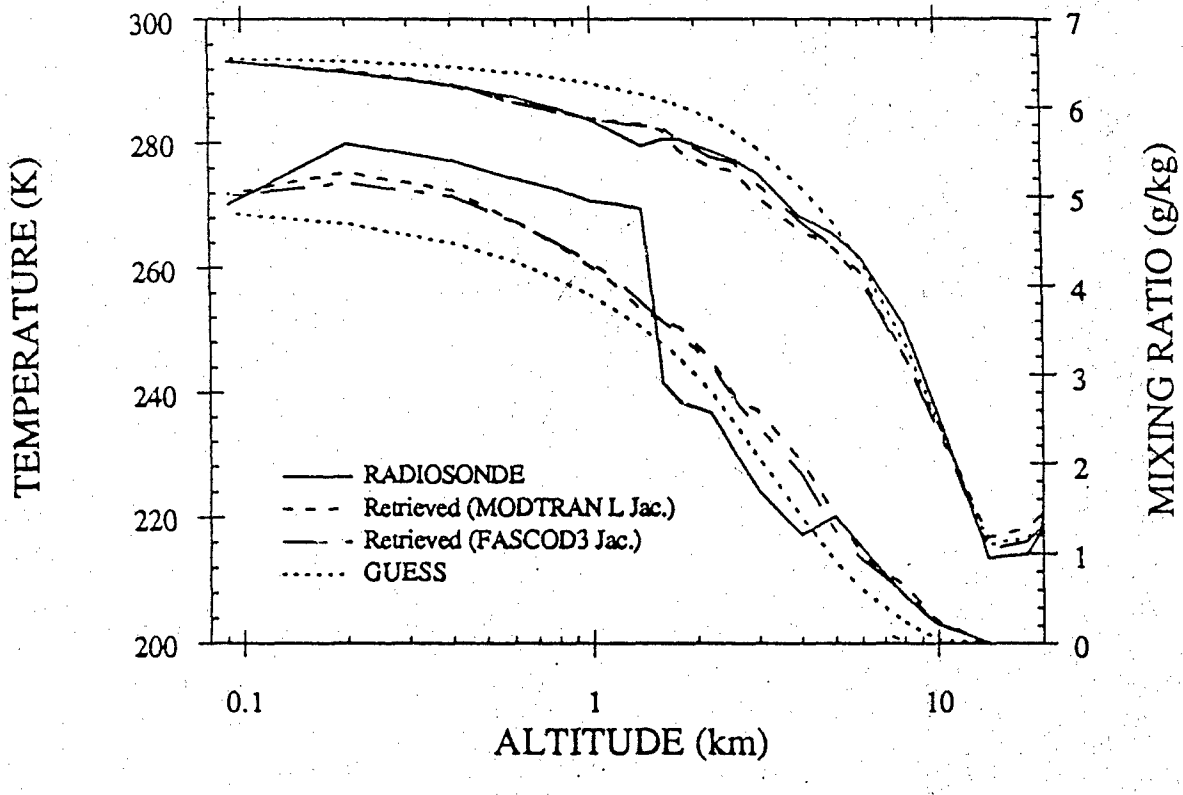
SIMULTANEOUS RETRIEVAL FROM MEASUREMENT j102a
709 Channels : First Guess= Radiosonde : Tuned Damping (4, 100, 2)



SIMULTANEOUS RETRIEVAL SIMULATION:
Hot Dry Case-jl02a
Res.= 1 cm-1 (3 Bands) : First Guess Estimation :
Tuned Damping (2, 100, 2)



SIMULTANEOUS RETRIEVAL (jl02a simulation):
FASCODE / VS / MODTRAN-L JACOBIANS:
Full Band 500-1400 cm-1 (2 cm-1)
Damping-T=100 : Damping-H=1



CONCLUDING REMARKS

- **MAIN ACHIEVEMENT:**

  - A Method (Minimum Information type) for the simultaneous retrieval of tropospheric profiles(T, H_2O) based on IR emission spectra measured from the ground has been developed and validated with experimental data (DBIS).

  - The method takes advantages of:
    1. Accuracy of FASCODE
    2. Spectral Screening that removes ambiguous spectral regions.
    3. Continuum correction (foreign broadening coefficients) at the edge of the 6.3 μm band of water.

  - MODTRAN possibilities have been established

- **FUTURE WORK:** Slant path and clouds studies
